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INFLUENCE OF THE SHOT PEENING PROCESS ON THE RESIDUAL STRESS AND MICROHARDNESS PROFILES IN AUTOMOTIVE GEARS MADE OF CEMENTED STEEL SAE 4130

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Abstract. *Shot Peening is part of the family of blasting processes widely used in surface treatment of parts and structures in the industrial field, being one of the most effective techniques in increasing resistance to fatigue. The Shot Peening process is one of the main steps in the process of producing components subjected to cyclic stresses and, consequently, failure due to fatigue. In this way, this work has as general objective to study the effects induced by the shot peening process in the relation between the microhardness and the residual stress steel JIS SCM 420 HV2. The Shot Peening process used in this work was "Air Blast" which can be described as the acceleration of ~~the~~ spheres by a jet of air in a specific nozzle, in which it is possible to control the speed and angle of impactof the spheres under the samples, a total of 30 samples were prepared in the shape of gears and treated thermo-chemically in a single batch, in order to guarantee the same cementing condition. These samples were characterized by tests of hardness and microhardness, surface and core. It was observed that the shot peening causes an increase of the microhardness to a depth of 0.06 mm, just as the peaks of compressive residual tension were obtained at a distance of 0.03 mm. It is observed that profiles with the same value of almen deflection, differ when the time of shot peening is long enough to occur the phenomenon of "over peening".*

Keywords: *shot peening, microhardness, residual stress, x-rays diffraction*.

1. INTRODUCTION

The "Shot Peening" process is one of the main steps in the production process of components subject to cyclic stress and, consequently, failures due to fatigue. The use of the term shot peening is universally accepted and derives from the intention to characterize that it is not a simple blasting, but a precision tool, which depends on a number of factors, which makes it rigorously controllable and repeatable (ALMEN and BACK, 1963). The shot peening process can be considered as a special process, where stresses are induced so that there is a life increment during fatigue situations. These stresses are in fact compressive and alter the conditions of propagation and nucleation of the cracks in the surface of the piece, region ~~is~~ always subject to the greatest work stresses, considerably increasing the life of the pieces during fatigue conditions (CALLE, 2004 and 2009). This work, in this context, contributes with greater knowledge about the shot peening process and its parameters effects on the residual stresses and, consequently, on the piece life during fatigue situations, on the increase of the microhardness, conditions that can lead to significant improvements to the resistance to wear.

2. METHODOLOGY

2.1. Materials

For this work, gears made of steel of co mmercial name JIS SCM 420 HV2 equivalent to SAE 4130 steel were used, according to chemical composition determined in standard. The steel was obtained with a forming die forged with some geometric measurements proximate to the final gear, subjected to ~~a~~ an annealing heat treatment with a hardness of approximately 255 HB and ferritic-pearlite microstructure as can be seen in Figure 1. The forged part is subjected to several machining steps: turning, milling, deburring and shaving, for the manufacturing of the test sample in the shape of a gear, and then subjected to the thermo-chemical treatments of cementation, oil tempering and tempering. After these steps the samples go through the shot peening process.

(a) 

(b) 

Figure 1. (a) Microstructure of material as received. (b) Testing body after the final finishing process with shot peening operation.

2.2. Methods

The Shot Peening process used in this work was "Air Blast" which can be described as the acceleration of spheres by a jet of air in a specific nozzle, in which it is possible to control the speed and angle of impact of the spheres under the samples. The spheres used were characterized by optical microscopy and Vickers hardness to verify if it was within that specified by the manufacturer. The SAE J442 standard says that in order to measure the size of the spheres, one must align 10 and then measure the total length, the sum of the ten beads must be between 5.81 mm and 6.13 mm in length. Almen blade height measurement technique was used to adjust the process parameters (pressure, coverage, flow), using an equipment manufactured by Eletronics Inc. model # 2 Almen Gage which has a micrometric resolution of 0.001 µm and steel blades type A with dimensions of L76.2xW19xT1.295 mm, where, w = width, t = thickness, l = length..

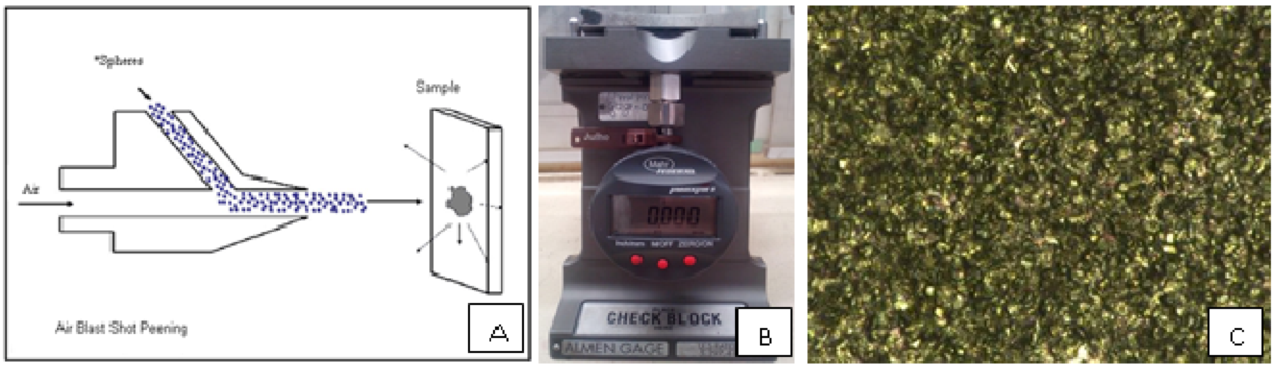

Figure 2. (A) Air Blast method scheme; (B) Almen Gage Eletronic Inc.; (C) Almen blade after shot peening process with 99 % coverage.

A total of 30 samples were prepared in the shape of gears and treated thermo-chemically in a single batch, in order to guarantee the same cementing condition. These samples were characterized by tests of hardness and microhardness, surface and core. This step was necessary to select the pieces with similar characteristics guaranteeing that all the samples submitted to the shot peening process had the same initial condition and that the hardness variations of these samples after the shot peening process were due only to the parameters of this process. Four test conditions were established, by combining two factors: the deflection of the almen and the coverage, a minimum condition of the equipment was defined provided that it guaranteed that the coverage was always at least 98 %. For this to be possible the distance between the nozzle and the primitive diameter of the gear was fixed and the direction of rotation of the gear anti-clockwise. In this way the angle of impact was 87°, the only parameter of the machine that was varied was the air pressure. As related parameters involve industry secrecy we will define in three processing conditions: minimum, intermediate and maximum. In regards to parameters where there are no changes we will keep as fixed. For the processing time we will establish that the condition of (1x) is the condition of one unit of optimal time, as described in Table 1.

Table 1. Test Parameters (Indicar quanto aumentou de pressão %)

Surface Conditions	Almen Height (mmA)	Pressure (MPa)	Rotating Speed (rpm)	Air Flow (kg/min)	Time (s)
1	MIN	MIN (A)	FIXED	FIXED	1X
2	INTERMEDIATE	INTERMEDIATE	FIXED	FIXED	1X
3	INTERMEDIATE	INTERMEDIATE	FIXED	FIXED	2X
4	MAX	MAX	FIXED	FIXED	1X

Next, the methodologies used in this step (Cut, metallographic preparation, hardness / microhardness and residual stress) and in the selected samples submitted to the shot peening process will be presented. The analysis of the microstructure and residual stress of the samples were performed for carrying out comparisons with the samples submitted to the shot peening process.

3. RESULTS AND DISCUSSION

The microhardness profile of the selected samples was analyzed transversally to a depth of 0.1 mm. Such depth was sufficient in order to verify the relationship between microhardness and residual stress. A good uniformity of the microhardness profile is observed in the results shown in Figure 3. The carburizing process followed by tempering had samples of very similar microhardness profiles selected, as well as the values of core hardness did not show great variation. (SILVA, 2016)

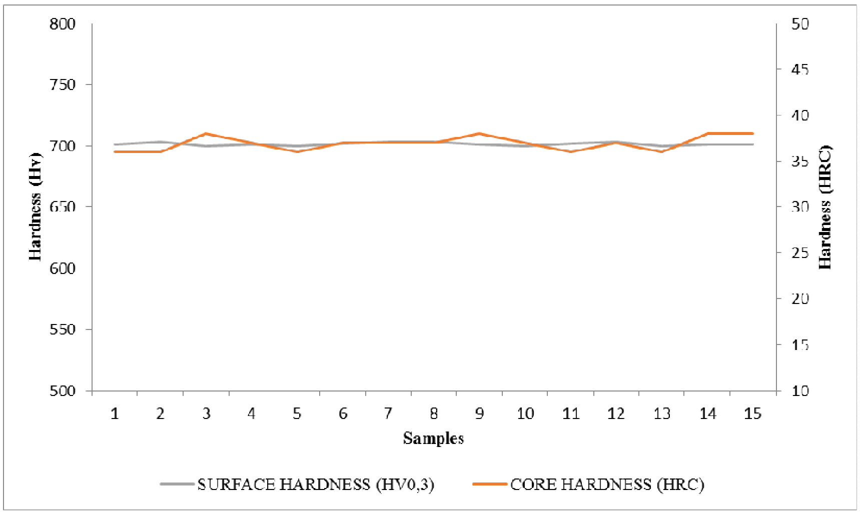

Figure 3. Core and surface hardness of selected samples.

The maximum value of the standard deviation of the profile points was 5 HV below the value specified by ASTM - E 384 (± 10 HV). The maximum microhardness was obtained after cementation of 712 HV with a depth of 0.01 mm, remaining in the range of 700 HV up to 0.03 mm, reaching up to 600 HV in 0.08 mm and a sharp reduction up to 500 HV in 0.1 mm, but even higher than the microhardness value of the 354 HV core. Therefore, for analysis criteria, depths up to 0.1 mm are adopted for all analyzes related to Vickers microhardness, as can be observed in figure 4.

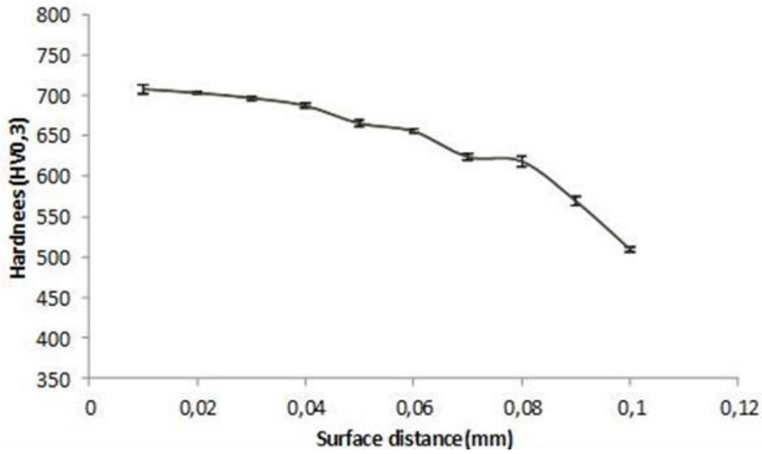

Figure 4. Graph of the average profile of microhardness of cemented samples.

The residual stress profile of the cemented samples is shown in figure 5. The mean values of residual stress are constant within the measured cemented layer. The mean value of residual stress measured up to 0.07 mm was of 356 MPa, with a standard deviation of ± 10,21 MPa, a condition that can be considered as optimal due to the homogeneity of the cemented layer and considering that the resolution of the x-ray diffractometer used is ± 60 MPa. It was expected to find compressive stresses in the material as a function of the carburizing operation, but these values may vary according to the chemical composition of the material and the process history in which the material was submitted before the cementation process (Griffiths, 2001). Within the cemented layer the measured residual stress remained constant.

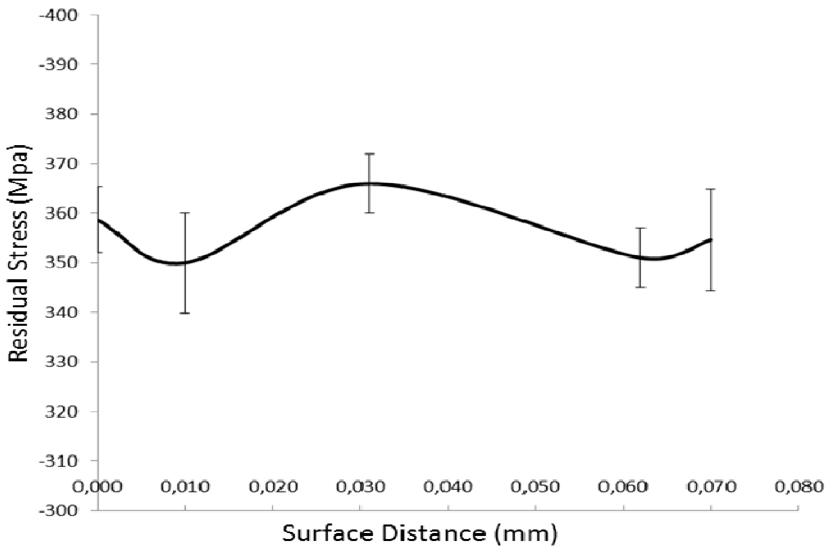

Figure 5. Average residual stress profile of cemented samples.

For the shot peening condition 1 (minimum) , the samples presented a sensitive increase in the microhardness profile, in relation to the only-cemented samples, with an average increase of 35 HV. This increase of hardness was already expected due to the hardening generated on the surface by the impactof the spheres. Near to the surface between 0.01 ~ 0.02 mm a trend of lower microhardness values is observed when compared with larger depths. As it moves away from the surface toward the core, this microhardness tends to rise and remain statistically constant with an average value of 750 HV to a distance of 0.06 mm, decreasing to microhardness values similar to those of only-cemented samples. As shown in the figure 6.

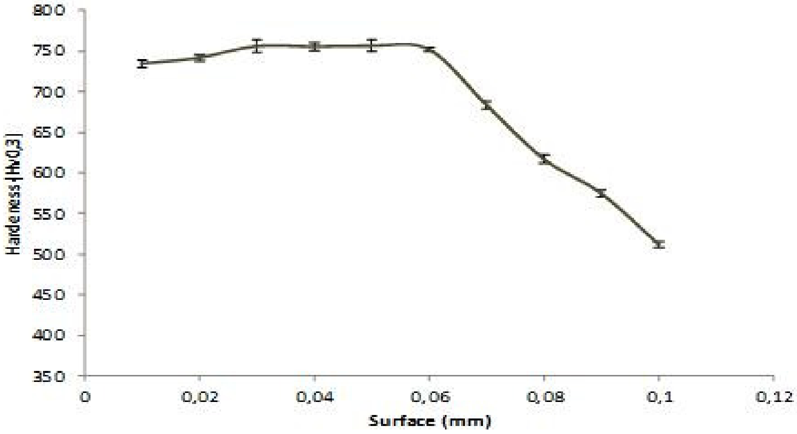

Figure 6. Average microhardness profile of the samples treated with shot peening in condition 1 (Minimum).

The figure 7 shows the profile of compressive residual stress generated in the part by shot peening in condition 1. It is possible to observe that there was the formation of the characteristic profile of parts that are submitted to the shot peening process. The mean value of compressive residual stress at the surface was -750 MPa, the maximum value of tension at a distance of 0.03 mm from the surface with a mean value of -982 MPa, from the point 0.03 mm the compressive residual tension has a reduction of its value reaching the point 0.07 mm with average value of -680 MPa, the average standard deviation being ± 27 MPa.

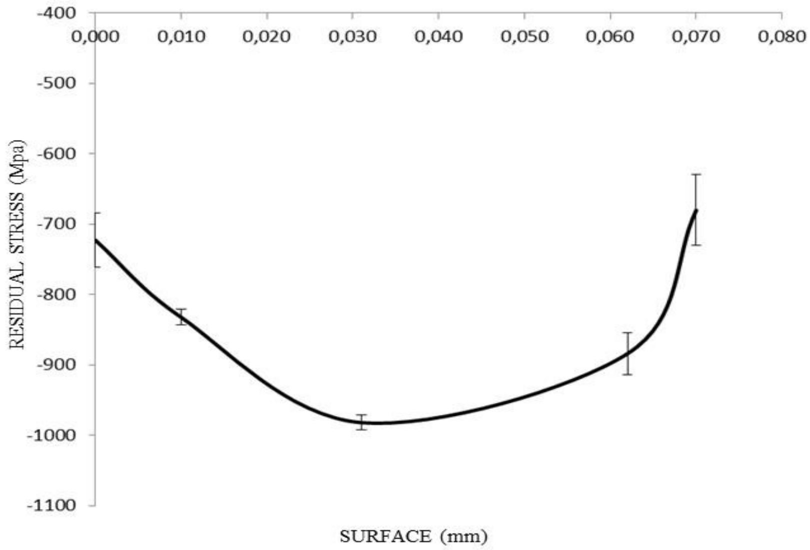

Figure 7. Residual compression stress profile for sample with shot in condition 1 (Minimum).

For condition 2 (intermediate), the profile of microhardness is similar to that of condition 1, but with higher mean values of microhardness. Near the surface between 0.01 ~ 0.02 mm with average values of 750 HV, and with average values of 790 HV up to a distance of 0.06 mm.

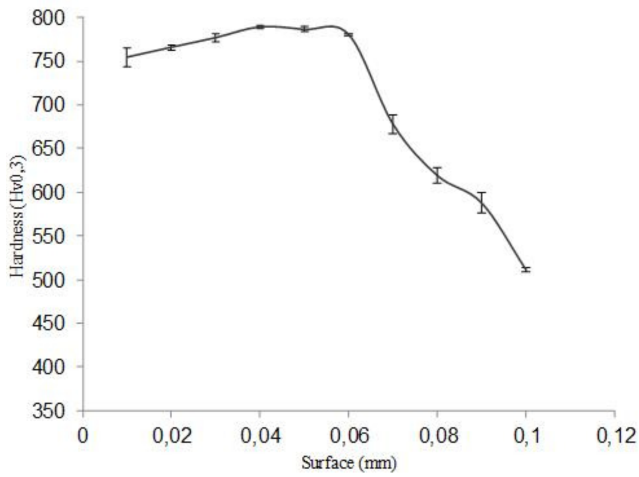

Figure 8. Average microhardness profile of the samples treated with shot peening in condition 2 (Intermediate).

The mean value of compressive residual stress had a significant increase in relation to the sample in condition 1 (minimum), in the surface this value was of -781 MPa, being the maximum value of compressive residual tension in the same distance of 0.03 mm of the surface with average value of - 1011 MPa, from the point 0.03 mm the compressive residual tension has a reduction of its value reaching the point 0.07 mm with an average value of -526 MPa, a value considerably smaller than the sample in condition 1 (minimum), with an average standard deviation of ± 24 MPa.

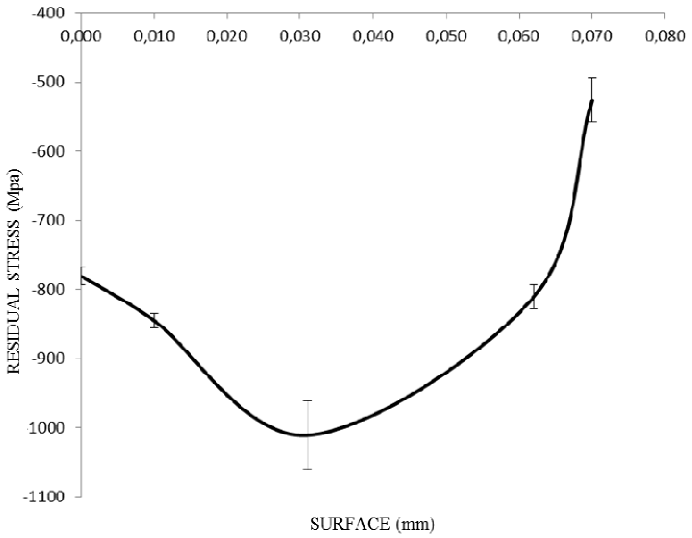

Figure 9. Residual compression stress profile for sample with shot in condition 2. (Intermediate 1x)

In this condition 3 (intermediate 2x) the microhardness profile is completely different from that observed in condition 1 (minimum) and condition 2 (intermediate). It is observed that profiles with the same value of almen deflection, differ when the time of shot peening is long enough to occur the phenomenon of "over peening" (BAGHERIFARD *et al*, 2013). Over peening is a phenomenon that occurs when components are subjected to long cycles of shot peening, where duration is longer than the one required for component saturation. When this happens, instead of providing the desired mechanical characteristics to the components, an inverse effect is obtained, that is, the components become fragile (TANGE and OKADA, 2002). Although it is a known phenomenon, it is not yet known exactly at what moment of the shot peening it happens, some scientists have dedicated in some research to try to create a mathematical model that explains the exact moment when shot peening ceases to be beneficial for the component.

Although there was an increase in the duration there was no significant bending in the residual stress profile, the profile being very similar to that of condition 2 (intermediate). The mean value of compressive residual stress at the surface was -721 MPa, the maximum value of residual compressive stress at the same distance of 0.03 mm from the surface with a mean value of -1032 MPa, from the point 0.03 mm the compressive residual tension has a reduction of its value reaching the point 0.07 mm with an average value of -548 MPa, a value significantly smaller than the sample in condition 1, with mean standard deviation of ± 49 MPa.

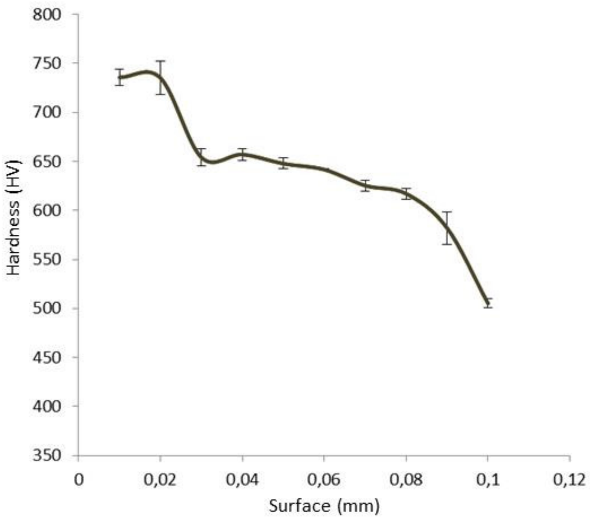

Figure 10. Average microhardness profile of the samples treated with shot peening in condition 3 (intermediate 2x)

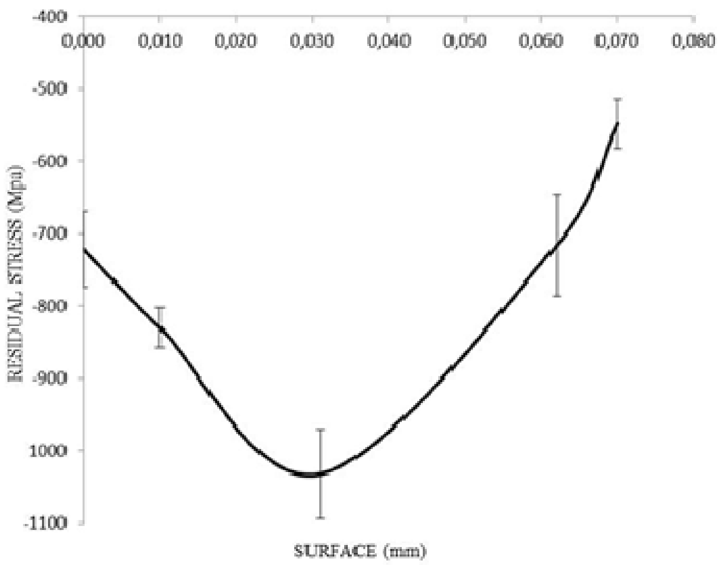

Figure 11. Residual compression stress profile for sample with shot in condition 3 (intermediate 2x).

In this condition 4 (maximum), the microhardness profile was similar to that of condition 1, however, with mean values of microhardness profile larger and with a profile similar to that of condition 2 (intermediate), including mean values . The compressive residual stress profile generated in the part by shot peening in process condition 4 (maximum). It is possible to observe that there were no significant changes and that statistically its profile is equal to the previous conditions. The mean value of compressive residual stress on the surface of this value was -674 MPa, the maximum value of residual compressive stress at the same distance of 0.03 mm from the surface with a mean value of -992 MPa, from the 0.03 mm point to the residual tension compressor has a reduction of its value reaching the point 0.07 mm with an average value of -723 MPa, with average standard deviation of ± 16 MPa.

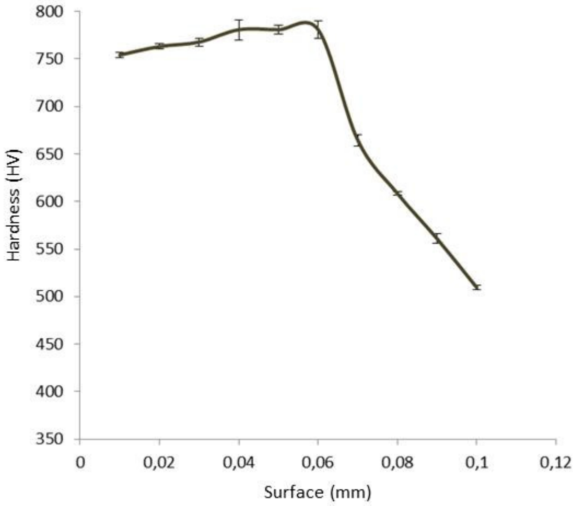

Figure 12. Average microhardness profile of the samples treated with shot peening in condition 4 (maximum).

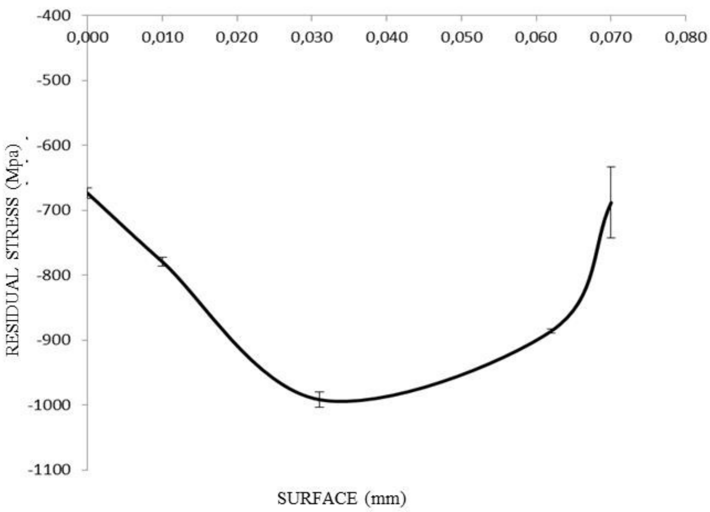

Figure 13. Residual compression stress profile for sample with shot in condition 4 (maximum).

With increase of the value of almen (condition 1, 2 and 4) a tendency of increase in the average values of the hardness profile is observed, being similar with values of almen above 0.4 mmA. In all shot peening conditions a change in the hardness profile was observed with respect to the cemented layer to a depth of 0.06 mm, remaining unchanged from 0.08 mm. For even values of almen (condition 2 and 3) varying only the time the effect of the "over peening" is observed.

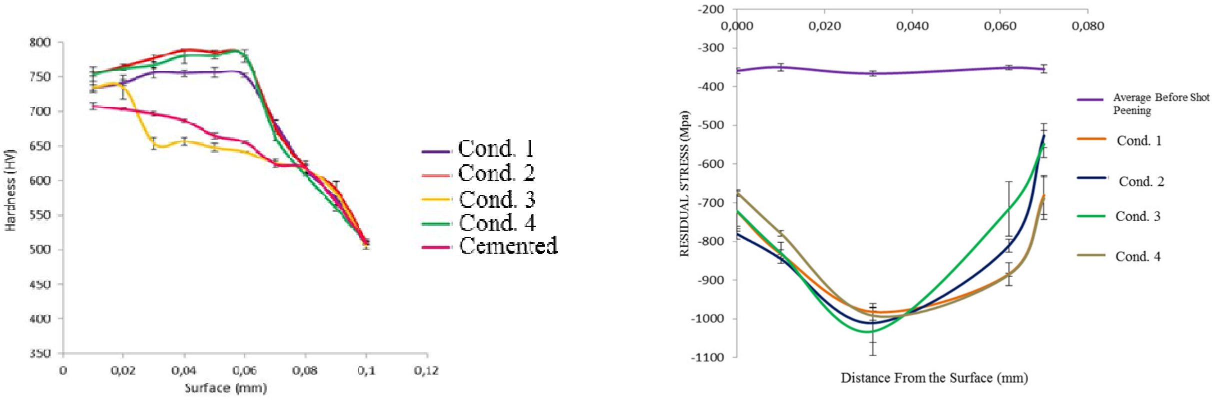

Figure 14. Co MParison of the different shot peening conditions with the samples only cemented.

Despite the variations, it is not possible to observe difference between the samples. Statistically, it can be stated that despite different conditions the compressive residual stress profiles have the same characteristics, that is, it has a residual surface tension ranging from -690 ~ 800 MPa, with the compressive residual pressure peak being 0.03 mm from surface area ranging from -900 ~ 1060 MPa, and, lastly, at a distance of 0.07 mm where the largest variations with compressive residual tension of -500 ~ -700 MPa were found. The profiles obtained can be compared with the profiles found by V. Llaneza, FJ Belzunce (2015), with a difference between the end point of measurement, in this work the strain measured to the point of 0.07 mm while V. Llaneza, FJ Belzunce (2015) have built a profile with greater depth. Compared to the results obtained by these researchers, those obtained by this work can be considered to be very close.

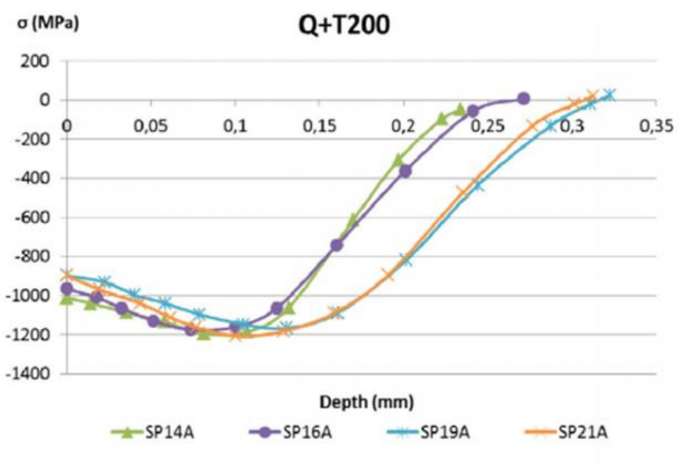

Figure 15. Residual tensile profiles obtained by Llaneza and Belzunce for a temperate sample and annealed at 200ºC. (LLANEZA, 2015)

4. CONCLUSIONS

- For all conditions of shot peening occurred an increase in microhardness, up to a distance of 0.06 mm from the surface, remaining unchanged from 0.08 mm. The only exception was condition 3 (intermediate 2x) with prolonged blasting time where the microhardness profile differed completely from the profiles obtained under the other conditions, due to a phenomenon known as "over peening". The profiles of microhardness in conditions 1, 2 and 4 can be considered similar. The highest values of microhardness were found at a distance of 0.03 mm from the surface for conditions 1,2 and 4.
- For all the conditions of shot peening process the residual stress profiles was similar, being the maximum peak at 0.03 mm, reaching -1099 MPa.
- For condition 3 (intermediate 2x), although the samples had suffered the "over peening" that is noticeable in the measurement of the microhardness profile, there was not that same indication in the results of residual tension.

- It was not possible to establish a correlation between the microhardness profiles and the residual stress profiles.

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